STUDY OF THERMAL NEUTRONS IN THE ATMOSPHERE.*

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ABSTRACT. The intensity of thermal neutrons in the atmosphere has been measured at the sea-level (Calcutta 70 ft.), and at a higher altitude (Darjeeling 7000 ft.), using a boron-lined proportional counter. A preliminary measurement of the size-frequency distribution of the energies of the disintegration particles from boron by the action of atmospheric neutrons has been carried out at the higher altitude with a boron trifluoride ionisation chamber

1. INTRODUCTION

Various investigators have reported the existence of neutrons associated with cosmic radiation, both at sea-level and at higher altitudes. Locher and Rumbaugh[1] sent up photographic films coated with paraffin during stratospheric flights. They observed proton tracks in the photographic emulsions, which they believed to have been caused by protons knocked out of paraffin by neutrons in the cosmic rays. E. Schopper[2] made a similar observation. Recently, W. Heitler[3,4] and his co-workers have investigated the nature of the radiation producing heavy cosmic-ray particles by means of the photographic plate kept exposed at Jungfraujoch under different thicknesses of lead plate. They come to the conclusion that there are at least two components in the cosmic radiation producing heavy particle, the first of which is very little absorbed in lead and consists very probably of neutrons. The other has a transition curve in lead very similar to that of the soft component of the cosmic radiation (electrons and light quanta). E. Fünfer,[5] using a boron-lined proportional counter and a proportional amplifier, determined the neutron intensity at the sea-level and reported a rapid increase of this intensity with elevation up to the top of Zugspitze, 2650 metres, corresponding to 7·5 metres of water. V. Halban, Kowarski and Magat,[6] measured the neutron intensity at higher altitudes, by studying the radioactivity induced in bromine to altitudes of about 3 metres of water. Recently, Korff[7] has developed new G.-M. counter methods for detecting thermal neutrons in radio-recording unmanned balloon flights, attaining a maximum altitude of ½ metre of water. For the detection of slow neutrons, he used argon-boron trifluoride mixture, which has got the special property of producing big pulses, even when the counter voltage is lowered about 200 volts

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below the threshold. C. G. Montgomery and D. D. Montgomery[8] used an ionization chamber, enclosed within a glass envelope and filled with BF_3 gas at about the atmospheric pressure. The alpha-particles resulting from the ${}_5B^{10}$ (n, α) ${}_3Li^7$ reaction produced voltage pulses which were recorded as galvanometer kicks in a photographic paper. The size-frequency distribution of the pulses was recorded. So far it was assumed that the disintegration of ${}_5B^{10}$ by slow neutrons took place only according to the reaction ${}_5B^{10}$ (n, α) ${}_3Li^7$, but recently Fisk and Maurer,[9] by means of detailed investigation have shown that another energetically possible reaction ${}_5B^{10}$ (n, p) ${}_4Be^{10}$ also occurred.

The present experiments were undertaken with the following objects in view:

(*i*) to determine the intensity of thermal neutrons at the sea-level and its variation with higher elevations,

(*ii*) to study the energy-spectrum of the particles produced during the disintegration of boron by slow atmospheric neutrons at high altitudes and to compare the results obtained with those of Fisk and Maurer.

The investigations are being continued, here a report is given of the preliminary results obtained.

II EXPERIMENTAL METHODS AND RESULTS

Two different sets of experiments were undertaken for the above purposes:

(*i*) The neutron intensity measurements at Calcutta (height 70 ft.) and at Darjeeling (height 7000 ft., equivalent water depth 8·1 metres from top of atmosphere), have been done with a boron-lined proportional counter tube and a proportional amplifier. It is proposed to extend the measurements to higher altitudes.

(*ii*) Preliminary measurements on the energy-spectrum have been made only at Darjeeling with an ionization chamber filled with boron trifluoride gas and a linear amplifier.

PROPORTIONAL COUNTER TUBE METHOD

The counter tube consisted of a brass cylinder of thickness 1·5 mm., internal diameter about 8 cms. and effective length 48 cms., with a central thin tungsten wire. The end-pieces consisted of ebonite plates with central plugs of amber and corresponding guard rings. The inner surface of the cylinder was coated with a layer of amorphous boron powder of thickness about 3·0 mgm. per cm^2. Such tubes were filled with argon, argon-tetrachloride and argon-boron trifluoride gaseous mixtures and the regions of proportionality for the tubes filled with the different gas mixtures were investigated. As found out by Korff, the sub-threshold region was found to be extremely narrow in the case of pure argon but spread over a range of voltage about 80 volts in the case of argon-boron trifluoride mixture over which ionization pulses could be observed. We got a plateau extending about 20 volts over which the number of neutron counts was found to be constant. The pressure used was 8 cms. (5 cms. BF_3 + 3 cms. Argon) and the voltage applied was about 1000 volts. The collecting electrode was directly connected to the grid of a R. C. A. 6J7G tube and subsequent amplification was done by two other stages of pentodes. A neutron in region of boron entering such a counter may cause the disintegration of a $_5B^{10}$ nucleus and the ionisation due to the products will be detected by the proportional amplifier. The pulses could either be heard in a pair of headphones capacitatively coupled or recorded as usual, in a telephone-meter. Counts were taken when the counter with the first vacuum tube was kept inside a metal-lined thin wooden box and again when the entire assembly was placed within a thick borax shield. In our case the residual back-ground count with the borax shield has been found to be very small compared to that found by Fünfer with his boron-lined proportional counter This may be partly due to careful polishing of the internal surface and partly due to the rather thick internal coating of boron (3 mgm./cm.^{2}) which absorbed the alpha-particles due to contamination of the material of the counter. At Darjeeling the counts were taken at the commencement of the monsoon when the humidity was near about 100% and so special precautions had to be taken to avoid spurious counts due to leakage.

TABLE I

	Within borax shield	Without shield	Neutrons per minute
Calcutta (70 ft.) ...	$0{\cdot}25 \pm 0{\cdot}02$	$1{\cdot}17 \pm 0{\cdot}05$	$0{\cdot}92 \pm 0{\cdot}06$
Darjeeling (7000 ft.) ...	$0{\cdot}4 \pm 0{\cdot}05$	$3{\cdot}5 \pm 0{\cdot}2$	$3{\cdot}1 \pm 0{\cdot}2$

IONISATION CHAMBER METHOD

An ionization chamber was taken in the form of a thin copper cylinder, 42 cms. long and 4·8 cms. in diameter, with a thin central wire as the collecting electrode. The whole system was enclosed in a glass envelope and filled with boron-trifluoride gas at about 57 cms. pressure. A steady potential of 600 volts was supplied to collect the ions. A linear amplifier, the details of whose construction will be described elsewhere, was used for the requisite amplification. The collecting electrode was directly connected to the grid of an electrometer tube. The voltage pulses caused by the disintegration of boron nuclei, were observed as kicks in a cathode-ray oscillograph. The lengths of the kicks were visually measured with the aid of a ruled transparent screen which could be placed against the fluorescent screen of the oscillograph. Evidently the measurements are not so accurate as those in which the voltage pulses are photographically recorded by a loop oscillograph. Two sets of observations were taken; once when the ionization chamber with its metal container was kept within a thick borax shield and again when the shield was removed. The difference gave the number of disintegrations of boron nuclei produced by atmospheric neutrons. Our ionization chamber being rather small in size, the sea-level intensity cannot be determined with precision. Use has been made of the sea-level data for neutrons obtained by Montgomery and Montgomery using a larger ionisation chamber. Table II gives the neutron intensity as measured at Darjeeling with the ionization chamber.

TABLE II

	Within borax shield	Without shield	Neutrons per minute
Darjeeling (7000 ft.) ...	1.37 ± 0.15	3.80 ± 0.22	2.43 ± 0.25

From Table II we find that the number of counts due to slow neutrons is $(2.43 \pm 0.25) \times 60 = 145.80 \pm 15$ per hour, for an ionisation chamber with an effective volume of 765 cms. and containing BF_3 gas at a pressure of 57 cms. To compare the relative intensity of the slow neutrons at Darjeeling and Calcutta, we proceed as follows :

If n is the number of counts per second of such a counter in the $\frac{1}{v}$ region, n is given by

$$n = \rho\sigma_B v_B . N p_B c_B V.$$

where σ_B is the capture cross-section of $_5B^{10}$ for neutrons of velocity v_B.

N is the Loschmidt number.

p_B is the pressure of BF_3 in the counter.

V is the volume of the counter in ccs.

ρ is the density of neutrons per cc. of all velocities within the energy range for which $\frac{1}{v}$ law holds.

We give below in Table III the data for neutron counts obtained by Montgomerys and ourselves.

TABLE III

Investigator	Altitude	Volume of ionisation counter in ccs.	Pressure cms.	No. of counts per hour.
Montgomery and Montgomery[8]	sea-level	1540	74	91 ± 7
Author ...	8·1 metres of water.	765	57	146 ± 15

Converted to the pressure and volume used in Montgomerys' investigation, our No. of counts per hour comes to about 388, and the ratio of the counts at

$$\frac{\text{Darjeeling}}{\text{Calcutta}} = \frac{388}{91} \sim 4.2.$$

Figure 1 depicts the size-frequency distribution of the energies of the disintegration particles from boron by the action of atmospheric neutrons. It is the difference between the size-frequency distribution curves of the particles when the ionization chamber is shielded with borax from that when the shield is uncovered.

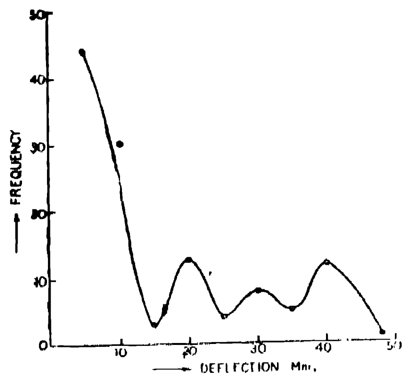

FIGURE 1

Comparison can be made with the energy-distribution curve found by Fisk and Maurer of the disintegration products of boron due to slow neutrons. The positions of the maxima found by them are at 0.4, 2.3, 2·5, 3·5 M. eV. and minima at 1.5, 3.2, 3.7 M. eV. Our energy-distribution curve is roughly in agreement with the above, only we have another maximum near 4.0 M. eV. According to the above investigators, the first maximum is attributed to the emission of protons, due to the process ${}_5B^{10}(n, p){}_4Be^{10}$, and other maxima are due to the emission of α-particles according to the reaction ${}_5B^{10}(n, \alpha){}_3Li^7$.

Further investigation is proceeding with a loop oscillograph for photographically recording the amplitude of deflections in place of visual observations with a cathode-ray oscillograph.

DISCUSSION OF RESULTS

We find the ratio of the intensities of cosmic-ray neutrons with the $\frac{1}{v}$ range of boron for the elevation of Calcutta and Darjeeling (8.1 metres of water) comes out to be

(*i*) with proportional counter $= \frac{3.1}{.92} \sim 3.4$ and

(*ii*) with ionisation chamber taking Montgomery and Montgomery's reading at sea-level, $\frac{388}{91} \sim 4.2$.

According to Korff, the ratio of the neutron intensity at altitude 8.1 metres of water to that at sea-level is about 3.9, which is comparable with our results. In our experiments we think our result with the ionisation-chamber counter to be more accurate than the result obtained with the proportional counter.

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